ADDRESS

Delivered by the President, Dr. J. W. L. Glaisher, on presenting the Gold Medal of the Society to Professor J. C. Kapteyn.

In awarding the Gold Medal of the Society to Professor J. C. Kapteyn for his work in connection with the Cape Photographic *Durchmusterung* and his researches on stellar distribution and parallax the Council have been able to place on record at the earliest opportunity their admiration of the noble services he has rendered to astronomy; and it is now my privilege to give a brief history of this great photographic catalogue and to refer to some of Kapteyn's other contributions to stellar cosmography.

In 1882 Gill tried the experiment of photographing the great comet of that year by means of a lens mounted in an ordinary camera, which was attached to the counterpoise of an equatorial. The successful results which he obtained suggested to him that with proper appliances photographic star maps could be constructed on any required scale and to any required order of magnitude.

During a visit to England in the early part of 1884 Gill obtained from Dallmeyer a rapid rectilinear lens of 6 inches aperture and 54 inches focus, this being the most suitable lens for astrophotographic work that Dallmeyer then had at his disposal. In September of the same year Gill applied for a grant from the Government Grant Fund of the Royal Society, partly for the purpose of photographing the solar corona and partly for making star maps by direct photography from the sky. With reference to the latter object he wrote: "I am most anxious to carry out this work for the southern heavens, being convinced that an accurate knowledge of star distribution according to magnitude can be more rapidly obtained in this way than in any other." The grant was made, and after some preliminary experiments systematic work was begun on April 10, 1885.

The first connection of Kapteyn with the work occurs eight months later. In a letter, written by him to Gill from Leyden on December 16, 1885, he made the following proposal: "If you will confide to me one or two of the negatives I will try my hand at them, and if the result proves as I expect, I would gladly devote some years of my life to this work, which would disburden you a little, as I hope, and by which I would gain the honour of associating my name with one of the grandest undertakings of our time." In a second letter, written a week later, after mentioning that at Groningen he is unprovided with an observatory, and sees no immediate prospect of obtaining one, he proceeds: "Now, after

your success in stellar photography, and especially after your letter in which you tell me, 'I am obliged to crave help where I can get it,' it has occurred to me that by measuring and reducing your photographs I could contribute very effectually towards the success of an enormous and eminently useful undertaking. Since then I have revolved the idea in my mind, and I have come to the conclusion that if you will let me, and if I can secure the necessary help, there is no one can be in better conditions to undertake the work than myself." In the concluding paragraph of the same letter, referring to the opinions of those he had consulted, he proceeds: "I am bound to say that they were not very enthusiastic about the matter; of course they thought the results once reached of immense value, but the drudgery to be gone through before these results are got into the form of a catalogue almost unbearable. However, I think my enthusiasm for the matter will be equal to (say) six or seven years of such work." As we shall see, Kapteyn did not overestimate his enthusiasm, which was to sustain him not only for six or seven years, but for nearly thirteen.

The actual photographing of the plates at the Cape, begun in April 1885, was continued without interruption until its completion at the end of 1890. There were several vicissitudes, principally relating to the lens. A second Dallmeyer lens of 6 inches aperture and 69 inches focus, which was expected to be superior to the first, was used for a time but found to be not so satisfactory. The portions of the sky, therefore, which had been photographed by it were rephotographed by the old lens, so that all the plates definitively used in the catalogue should be the work of the same lens.

The principal object which Gill had in view may be briefly described as the extension of the Bonn *Durchmusterung* to the south pole. To determine the exposure necessary for this purpose an area in the Bonn *Durchmusterung* was selected and photographed. The negative was then compared star by star with Argelander's chart, and the duration of the trial exposures was gradually increased till it was certain that every star in the selected part of the chart was shown as a measurable disc on the plate photographed from the sky. It may be mentioned that when the negative from the sky showed nearly the whole of Argelander's stars it also showed a great many more, as the Bonn *Durchmusterung* only professes to be complete as far as stars of the 9·2 magnitude.

Different kinds of plates were used during the five years over which the work extended. At first an exposure of an hour was required, but after about a year and a half more rapid plates were used, and the exposure was greatly reduced. At the time when the work was begun the difficulties were much greater than they would be now; the remarkable difference between the actinic and visual light of stars in different regions was unknown, as also was the variation of the sensibility of the plates due to moonlight

and other causes. Every area was photographed on two different nights in order to avoid the possibility of a speck on the plate being mistaken for a star.

I pass now to Kapteyn's work at Groningen : the measurements of the stars on the plates, their reductions, and the formation of the catalogue.

All the measurements for the catalogue were made by an instrument designed by Kapteyn for the purpose. The principle of this instrument, the object of which was to measure spherical coordinates directly from the plate, occurred to him very soon after he had received the first plates ; it depends upon the obvious fact that by placing a plate at the proper distance (that is, at the focal distance of the photographic telescope), with the film farthest from the eye, it is possible to cover the stars in the sky with their corresponding images. If, therefore, we substitute for the eye an instrument by which spherical coordinates can be measured in the sky, we can measure these coordinates as well on the plate as in the sky.

This instrument was employed in the early part of 1887 to measure the circumpolar plates (which were those first taken) to the tenth of a minute of arc, and it was found to be rapid and convenient in use and to give results of the accuracy required for a *Durchmusterung*. It was also shown that the stellar images were sufficiently sharp to be easily measurable to a second of arc, and a parallactic instrument capable of giving results to this degree of accuracy was devised by Kapteyn and Gill. It was, however, not constructed, and the whole of the measurements were made, to the tenth of a minute of arc, by the same instrument by which the circumpolar plates had been measured. In using this instrument Kapteyn always fixed two plates, corresponding to the same portion of the sky, in the plateholder, one in front of the other, at the distance of a millimetre. Small motions were provided, by means of which the corresponding star images of the two negatives could be brought nearly, but not quite, to superposition, so as to appear in the telescope like double stars, and thus true star images were at once distinguishable from accidental specks on the plates. Of these two plates, in case of the slightest difference, the one on which the images were more dense was employed to act as the check plate ; the other, mounted in front, was used as the measuring plate. The observations were made in a darkened room, the plates being illuminated from behind by a powerful lamp. The plates were square with a side of about six degrees.

In measuring the plates two observers always worked together, one at the ocular, one at the microscope of the hour circle. A clerk wrote down all the numbers called out by the two observers in ledgers prepared for the purpose. The observer at the ocular estimated the diameter, read off the declinations on the scale, and made the pointings for right ascension. These were read off by the observer at the microscope. Three or four

hours in the morning and three hours in the evening were generally devoted to the observations.

Every plate was observed twice, the two observations being quite independent. As soon as the second observation of a plate was completed the two observations were compared and the discrepancies examined. The second observations and the examinations and revisions were invariably made by Kapteyn himself.

The diameters of the images of the stars were estimated to tenths of a minute of arc. This unit, however, being found too large in practice was subdivided into thirds. From these diameters the magnitudes of the stars were determined by an empirical formula involving two constants, which will be referred to later.

Great pains were taken that no speck on the plates should be treated as a star; so careful indeed was Kapteyn in this matter that, as he states himself, many thousands of objects, by far the greater part of which are certainly true stars, have been lost to the catalogue. But it was his settled policy from the beginning not to introduce any object that was not a true star, and rather to lose ten real stars (of the very faintest class) than to incur the danger of introducing a single fictitious one.

Having now described in general terms the manner in which the plates were taken at the Cape, and observed and reduced at Groningen, I have to speak of certain special difficulties under which the work was carried out. As already mentioned a grant from the Government Grant Fund was made in 1885. The grant was repeated in 1886, but not in 1887. In that year the International Astrophotographic Congress had decided to undertake the work of forming a catalogue of stars to the 11th magnitude, and making charts of the heavens approximately to the 14th magnitude. It may have been thought by some that Gill's project was superseded by the decision of the Congress, but he himself never doubted the desirability of his own work, believing that in the existing state of astronomy its urgent need was increased rather than diminished by the results of the Congress. The completion of the work, however, without external assistance taxed even Gill's energy and resourcefulness to the utmost. Fortunately he persisted to the end; but he was unable to have the parallactic instrument constructed that would have measured the plates to a second of arc, and he did not carry the work north of the declination $-18°$.

Kapteyn obtained some assistance from the Dutch Government and from several Dutch institutions, which enabled him to retain the services of two and sometimes three assistants. Only one, however, remained with him throughout; the others, who were all at first quite inexperienced in work of the kind, frequently left after a short time, and these frequent changes added to the difficulties, and delayed the progress, of the work.

At length the catalogue was completed and published, forming three volumes of the Annals of the Cape Observatory. The

first volume bears the date 1896, the second 1897, the third 1900. The catalogue includes all stars down to about the 9·5 magnitude from −18° to the south pole. It has been mentioned that Gill's object was to extend Argelander's *Durchmusterung*, which was published in the middle of the last century, to the south pole, giving the magnitudes and approximate positions of the stars. Argelander's work, which included stars to the 9th or 10th magnitude, contained 324,188 stars; Schönfeld, who continued the catalogue from −2° to −23°, included 133,659 stars between these limits. The Cape *Durchmusterung* contains 454,875 stars between −18° and the south pole.

The catalogues of Argelander and Schönfeld contain 431,760 stars for the rest of the sky. The average number of stars for each square degree in the Cape, Argelander, and Schönfeld catalogues is 32·66, 15·19, and 18·21 respectively, so that the star density in the Cape catalogue is more than double as great as in Argelander's catalogue. The latter catalogue set a good example as regards freedom from errors, and there is every reason to believe that Kapteyn has fully maintained this high standard in the present volumes.

It is difficult to speak in too high terms of the zeal and ability displayed by Kapteyn during the years that he devoted to this catalogue. In the preface to the third and last volume Gill refers to him in the following terms: "It is my colleague and friend, whose name appears on the title page, to whom I am under the deepest obligation. At a time of great stress and discouragement he lifted from my shoulders a load of responsibility by his noble and spontaneous offer to undertake the measurement of the plates, the computation of the results, and the formation of the catalogue. He realised from the first the advantages and possibilities of the work, as well as the need for it in the present state of science, and he devoted over twelve of the best years of his life to the fulfilment of his undertaking. I now realise that my many other duties, and the difficulty of obtaining adequate assistance, would probably have compelled me to defer a great part of the work of the catalogue to the years of my retirement from official life, and might even have prevented its completion.

"I feel assured that Kapteyn has not laboured in vain, and that astronomers will duly appreciate what he has done for their science."

I may here also quote Newcomb's words: "This work of Kapteyn offers a remarkable example of the spirit which animates the born investigator of the heavens. . . . The years of toil devoted to it were, as the writer understands, expended without other compensation than the consciousness of making a noble contribution to knowledge, and the appreciation of his fellow astronomers of this and future generations." *

* *The Stars* (1901), p. 49.

Indeed we do appreciate his spirit and his work; and we are delighted to have the means of expressing our appreciation as a Society to Kapteyn in person here to-day. Sustained by his enthusiasm for the value of the work, he did not shrink from carrying out himself the monotonous and anxious labour of making the measurements and comparisons, so that the catalogue has the great advantage of being the work of a single mind, incessantly devoted to securing the best results that the data could afford. If the enormous amount of work required by the measurements may, perhaps, be described—as it was by Kapteyn's friends at the outset—as drudgery, it was quite otherwise with the methods of procedure, many of the questions to be dealt with being novel and full of interest, as this was the first photographic catalogue. The most important of these questions related to magnitude, and it fell to Kapteyn to have to investigate in much detail the relation between photographic and visual magnitudes.

By comparing the variation of star-density as determined from the plates with the variation as determined by the visual observations of Schönfeld and Gould, he found that in some regions the plates contained three times the number of stars given by Schönfeld in the same area, while in other regions Schönfeld's catalogue was the richer, containing almost double the number of stars shown on the plates. He also found that, corresponding to these variations in the numbers of stars, there were similar variations in their brightness, equal diameters on the plates being produced by stars of very unequal brightness, in different parts of the sky. It is possible, as suggested by Thome, that the cause of these variations is purely observational, the visual observer not including so many very faint stars in the richer, as in the poorer, regions of the sky; but Kapteyn considers any such explanation quite inadequate, and concludes definitely that the difference between the visual and photographic magnitudes is largely dependent upon the position of the stars relative to the Milky Way, and that, even when we take into account only stars of one and the same spectral type, those in the Milky Way are in general bluer than the stars in other regions of the sky.

The magnitudes were deduced from the diameters by the empirical formula $m = \frac{B}{d+C}$, d being the diameter of the image and B and C constants which were determined for each plate by comparing a number of stars with the magnitudes in Schönfeld's catalogue or in Gould's zone catalogue. This formula gives good results for stars between the magnitudes 6·5 and 9·5, but the uncertainty increases rapidly beyond these limits. The same formula has been used for the whole catalogue, the values of B and C being given for each plate, so that it will be easy to make the necessary corrections when a better formula is known or even to fall back, if need be, upon the quantities

really measured—that is, on the diameters of the stars on the plates.

With respect to the limits of magnitude to which the catalogue may be considered complete, Kapteyn concludes that the whole catalogue is complete to stars of the photographic magnitude 9·2, and that it will be found practically complete in or near the Milky Way to stars which in the scales of Gould, Schönfeld, and Thome are of the magnitude 9·5, and for the rest of the sky to stars actinically equivalent to these.

In the catalogue itself it is noted when a star is suspected of being double, or variable, or nebulous, and references are given to the principal catalogues in which a star has previously appeared. A characteristic feature of the work is the extreme fulness of detail of the introductions, which, in addition to everything that can render the catalogue more serviceable, contain the results of extensive comparisons with catalogues of precision; such, for example, as lists of stars of the magnitude 9·0, or brighter, not found in the plates. Since the publication of the catalogue Kapteyn has been occupied with the formation of lists of errors in the other catalogues, lists of stars with large proper motions, and of variables, as also with an examination of the colours of the stars in the Milky Way. These investigations are practically complete. I may mention that it was by such comparisons that the star with greatest known proper motion ($8''\cdot70$) was discovered.

Thanks to the enthusiasm and perseverance of Gill and Kapteyn, we are now in possession of the Cape *Durchmusterung*. No doubt in the fulness of time it will be superseded by the astrographic chart of the heavens, which will not only include many more stars, but give their places with precision; still it is a great matter that such a fund of information as the Cape catalogue supplies should have been rendered available at such a comparatively early date to the workers of our time. For the adequate treatment of the great cosmical problems relating to the magnitude and distribution of the stars, extreme accuracy of position is not required, and for all such investigations the Cape catalogue affords abundant material.

Before leaving the subject of the catalogue it should be mentioned that the whole of the measurements of the plates, and by far the greater part of the computations, were carried out in two rooms of the Physiological Laboratory at Groningen, which were kindly placed at Kapteyn's disposal by his colleague, Professor Huizinga. These two rooms constituted what was at that time a novel form of observatory—the possibility of which we owe to photography—in which the instrument was applied to the observation of the plates, instead of the stars themselves.

It is natural in this place to refer to an examination of the Cape *Durchmusterung* by Newcomb, who, after remarking that in the completeness with which it covers the field we have nothing equal to it in the northern hemisphere, expresses the

opinion that it can hardly be supposed that any object photographically brighter than the 9·5 magnitude has failed to be included. From a comparison with Thome's Cordoba catalogue he concludes that the limiting magnitudes of the different plates are in reality more nearly uniform than they were taken to be (in order to represent correctly both the brighter and fainter stars), and that it may be regarded as a fairly complete representation of the southern sky to a photographic magnitude of probably 10·0. This discussion of Newcomb's shows how greatly stellar research has been facilitated by the clearness and fulness with which the data of the catalogue have been presented.

At the time when Kapteyn made his proposal to Gill in 1885 he was occupied at Leyden with the determination of stellar parallaxes. His observations related to 45 stars, and he obtained 15 parallaxes, four of which had been previously determined by other observers. He employed a transit instrument and chronograph, and came to the conclusion that by his method he could obtain results comparable to those given by the heliometer. He suggested a plan for determining the parallaxes of all stars to the 5th magnitude. Each star was to be compared with two stars of the 8th magnitude. The whole scheme involved 16,640 complete observations, which he calculated could be carried out by two observers in eight years.

In 1889 Kapteyn proposed a much more comprehensive scheme—viz. that each plate for the astrographic catalogue should be exposed at three successive epochs of maximum parallactic displacement, being carefully preserved in the intervals of six months and developed after the third series of exposures. The plates would then furnish, in addition to the position of the stars, a first determination of their parallaxes. The proposal was not adopted for the catalogue work, but Professor Donner undertook to obtain with the astrographic equatorial at Helsingfors a series of plates for a definitive trial of this method of obtaining parallaxes *en bloc*. These plates Kapteyn measured at Groningen, and he obtained from them a first determination of the parallaxes of 246 stars. After giving a careful and detailed investigation of the results, he considers the possibility of a general *Durchmusterung* for parallax to include all stars down to the 10th magnitude, about 800,000 in number. This, he thinks, would secure about 500 well-determined parallaxes. Kapteyn's project breaks new ground and raises many questions; his own discussion, however, greatly narrows the issues for those who follow him upon these lines.

There is a great deal of other work connected with stellar parallaxes and proper motions upon which Kapteyn has been engaged, much of which still remains unpublished. As the direct determination of stellar parallax has not as yet given results on anything like the scale required for the purpose of judging of the relative distances of the stars, we are compelled to resort to the parallactic displacement caused by the motion of the solar

system in space. This parallactic motion, however, cannot be separated from the real proper motion for individual stars, but there is every reason to think that the real proper motion shows very little preference for determinate directions, and it may therefore be assumed that, in the mean results obtained from small groups of stars, these real proper motions will destroy each other, leaving only that part which is due to solar motion, and it is this parallactic displacement that gives the most reliable measure of the mean distance of the stars under consideration.

If we transform the proper motions from right ascension and declination to motions in the apical direction (*i.e.* along the great circle joining the star to the solar apex) and perpendicular to it, it is clear that the former is affected by the parallactic motion, but that the cross motion, perpendicular to the apical direction, gives the true component of the motion of the star. Led by these considerations Kapteyn undertook the labour of resolving in the apical direction and perpendicular to it the proper motions of the 2357 stars in Draper's catalogue of spectra, which are also included in the Bradley-Auwers catalogue, and were observed both in right ascension and declination. The stars were taken from Draper's catalogue because Kapteyn had decided to divide them into groups according to their spectral type, and to consider the groups separately. This division has shown that stars with small proper motions belong generally to the first type, and those with large proper motion to the second. It may be that the stars of the second type are moving faster than those of the first, but it seems more probable that they are less distant. This gives some support to Gould's suggestion that the Sun is a member of a star cluster.

I must necessarily pass over other important papers of Kapteyn's upon the distribution of cosmical velocities, the distribution of stars in space, the statistical relations between parallax, proper motion, and magnitude, and upon the luminosity of the stars. As a detail in his larger statistical researches he has deduced the position of the solar apex by a new method (Kapteyn's method), in which the apex is so chosen that the sum of the proper motions resolved in the direction of the anti-apex is a maximum, or that the sum of the motions perpendicular to this direction is zero. The resulting apex is $\alpha = 273°{\cdot}6$, $\delta = 29°{\cdot}5$ as deduced from 2640 Bradley stars and 699 Porter stars. The discrepancy from Porter's result (obtained by Kapteyn's method), $\alpha = 280°{\cdot}5$, $\delta = 49°{\cdot}3$, and from Campbell's result $\alpha = 277°{\cdot}5$, $\delta = 20°{\cdot}0$, derived from spectroscopic determinations of velocity in the line of sight (280 stars), only shows, what might have been expected, that considerable groups of stars in different parts of the sky are affected by common drift, which is quite distinct from parallactic motion.

I need not do more than merely refer to Kapteyn's simple and ingenious suggestion in explanation of the phenomena of Nova *Persei*, which has been discussed so recently, and with so much interest, in this room.

It will have been seen that one spirit runs through all Kapteyn's work, viz. an effort to treat the great cosmical problems comprehensively, and to apply to them general methods which, though not exact, may be expected to give information which would be quite unattainable by any procedure resting upon an absolutely sure foundation with respect to every individual star. Always occupied with the most effective means of attacking the great problems of the universe, he has never flinched from the heavy labour required to carry his ideas into practice ; and it is very fitting that one whose mind has been from the first so much attracted by the more difficult questions presented by the statistics of the heavens should himself have contributed such invaluable material for the study of the subject which he has so much at heart.

The President then, delivering the medal to Professor Kapteyn, addressed him in the following terms :—

Professor Kapteyn, in placing in your hands this Gold Medal I wish specially to congratulate you upon the completion of the Cape *Durchmusterung*, and to express to you the hope that your life may long be spared, and that you may have health and strength to extract from this grand storehouse of your own formation many more of the great cosmical truths which it implicitly contains, and to enrich still further by your labours the important branch of our science to which you have devoted your life.

In handing to Dr. T. D. Anderson the Jackson-Gwilt medal the President addressed him as follows :—

Dr. Anderson, it is a great pleasure to me to hand you on behalf of the Society the Jackson-Gwilt medal in recognition of your discovery of both Nova *Aurigæ* and Nova *Persei*. Nova *Aurigæ* was discovered by you on February 1, 1892, when of the 4th magnitude, and but for your discovery it might have escaped observation. Nova *Persei* was discovered on February 22 of last year at 2.40 A.M., when of the 2·7 magnitude and low down in the sky. This early discovery of yours made it possible for Pickering to obtain its spectrum before its maximum was reached.

It is no small matter to have discovered one of these Novæ, but it is a veritable *tour de force*, such as *à priori* would have seemed almost incredible, to have discovered both, and I am delighted that we have the opportunity to congratulate you on your success and do honour to your astronomical zeal and intimate knowledge of the sky. Between your two discoveries several new stars had been found at Harvard, but all by photography.

I ought, perhaps, to refer at greater length to the number of variable stars—no less than thirty-eight—that you have discovered ; but on the present occasion I should prefer to restrict myself to the subject of the award, your wonderful discoveries of the two great Novæ of our time.